Nonlinearly Induced Refractive Index Measurements by Using a Probe Beam

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Abstract

We investigate nonlinearly induced refractive index variation in different ways. Self phase modulation creates far-field diffraction rings which are observed by focusing a cw Ar-Ion laser on to a sample with thermal nonlinearity. Simultaneously, the sample is probed with a low power He-Ne laser, and shows two sets of diffraction rings in the far field. The experimental results are simulated by solving the steady state heat equation. Information about the induced refractive index change can be determined from the probe beam far field pattern. Additionally, an interferometric technique is set up to determine the induced refractive index change.

Introduction

Self phase modulation is a nonlinear effect that can be observed when a high power laser beam is focused on to a high-absorbing thermal medium. The refractive index of the medium changes due to the heat generated by the focused laser (pump) beam. The whole process causes the thermal medium to act as a lens which is usually called a thermal lens. This thermal lens can create the diffraction ring patterns when a laser propagates through it.

Objective

The objective of this project is to observe these ring patterns by another laser beam travelling through the material in the opposite direction and explain theoretically by using computer simulations.

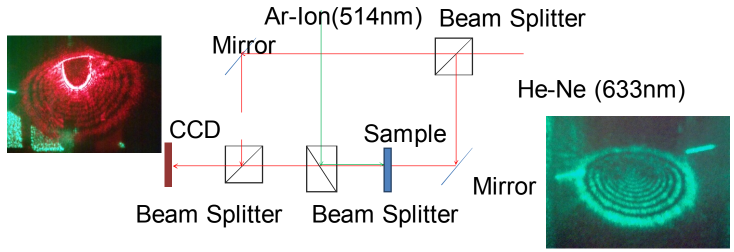
Methodology

➢ Experiment

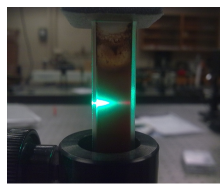
For the experimental part, a simple experiment is set in the lab using a high power Argon laser and it is focused to a regular tea sample. A plastic cuvette is used as a container. A Low power Helium-Neon laser (633nm) is then shined from the other side of the sample while the intense Argon beam is focused on to the tea sample. The green Argon laser which has a wavelength of 514nm is focused using a 300mm plano-convex lens.

Ring patterns are observed about 30cm away from the cuvette. This can be considered as far field compared to the Rayleigh range of the beam which is 6.28mm. Caculated beam size at the focus (w_0) for the Argon laser is 32µm.

➢ Experimental Setup



Intensity ring patterns are recorded on a normal digital camera as well as with a CCD camera from each side of the sample. It can be clearly seen that there are two sets of rings with the unfocused Helium Neon (red) laser beam. A filter that filters green color is also used to see the rings evolve from the probe beam. Ring patterns are observed in different powers of the Argon Ion laser.



(a)

(b)

Photographs of the tea sample (a) without a filter (b) with a filter (Filter is used to see the focused high power Ar-Ion beam clearly.

➢ Theory

Obtained ring patterns are simulated using MATLAB©. Fresnel–Kirchhoff diffraction integral (1) and the Fraunhofer approximation of that integral (2) are used for the simulations.

$$U(x,y)=\frac{e^{ikz}}{j\lambda z}e^{\frac{jk}{2z}(x^2+y^2)}\iint_{allspace}U(x',y')e^{\frac{jk}{2z}(x'^2+y'^2)}e^{-j\frac{2\pi}{\lambda z}(xx'+yy')}dx'dy' \quad (1)$$

$$U(x,y)=\frac{e^{ikz}}{j\lambda z}e^{\frac{jk}{2z}(x^2+y^2)}\iint_{allspace}U(x',y')e^{-j\frac{2\pi}{\lambda z}(xx'+yy')}dx'dy' \quad (2)$$

Heat equation (steady state) is solved to obtain the temperature profile inside the nonlinear sample. (at the boundary $r=a, dT=0$)

$$\nabla^2 T(r) = -\alpha e^{-\frac{2r^2}{w^2}}$$

$$dT = \frac{\alpha w^2}{8}\left[Ei\left(-\frac{2r^2}{w^2}\right) - Ei\left(-\frac{2a^2}{w^2}\right) - 2\ln\left(\frac{r}{a}\right)\right]$$

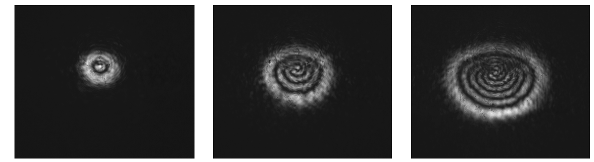
$$\Delta n = n(r) - n_0 = \frac{dn}{dT}\Delta T(r)$$

Field right after the sample, $E(r)\approx e^{\frac{-r^2}{w^2}}e^{-jk_0\Delta n(r)L}$

For the far field, $\Im[E(r)] = \Im\left[Ge^{-jk_0\Delta n(r)L}\right]_{k_x=\frac{k_0x}{z},k_y=\frac{k_0y}{z}}$

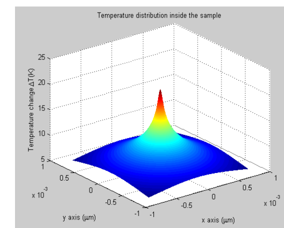
Results

Ring patterns obtained for different pump powers

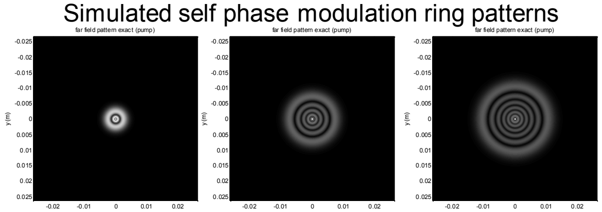


100mW 200mW 300mW

Temperature profile (from the heat equation)



Simulated self phase modulation ring patterns



100mW 200mW 300mW

Future Work

➢Simulate the ring patterns observed from the probe beam.
➢Find the refractive index change using interferometric technique.
➢Use this method to check the purity of Nonlinear samples.

References

➢Raj M. Misra and Partha P. Banerjee, Theoretical and experimental studies of pump-induced probe deflection in a thermal medium, Applied optics, Vol. 34, No. 18,20 June 1995.

➢R Karimzadeh, Spatial self-phase modulation of a laser beam propagating through liquids with self-induced natural convection flow, Opt. 14 (2012) 095701.